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A variable potential porous silicon carbide hydrocarbon gas sensor

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Abstract. A sensor which is capable of detecting hydrocarbons and distinguishing among them at temperatures in the range 100 - 400°C has been constructed using hexagonal (6H) silicon carbide (SiC). The sensor was tested in pure methane and pure propene and in 0.5% concentrations of these hydrocarbon gases in argon. The operation of the sensor is based on adsorption and reaction of hydrocarbons in a layer of porous SiC that has been photoelectrochemically etched in the surface. Experimental data show that it is possible to detect the presence of and identify the two hydrocarbon gases in pure gas streams and in lower concentrations of these gases. In principal, it is possible to distinguish among gases in a mixed stream. The ability to detect hydrocarbons and discriminate among them has applications in monitoring automobile emissions as well as monitoring functions in various process industries.

1. Introduction

Semiconductor based sensors such as those made from SnO_2 are well known, and are capable of detecting oxygen containing compounds such as CO and CO_2 as well as hydrogen containing compounds such as NH_3 and H_2 [1]. Such sensors are also able to detect hydrocarbon compounds, but are not able to distinguish among them. Recent developments in silicon carbide material growth technology make it possible to construct sensors using SiC as the electronic material as well as the active material in a gas sensor. The importance of SiC is based upon its ruggedness and durability, as well as its potential for use at high temperature (much greater than 300°C) and power levels. In addition, SiC has excellent electrical and thermal characteristics.

A capacitor-type sensor based on a catalytic surface attached to a SiC substrate has been constructed and tested by Arbab, *et al.* [2]. That sensor was able to detect the presence of several hydrocarbons in pure streams or in low concentrations in air by measuring the potential at a fixed capacitance. It requires high temperatures (> 500°C) for catalysis, and it is not clear that the sensor is able to distinguish among hydrocarbon compounds in the gas stream.

The sensor to be discussed in this paper is based on dissociation of hydrocarbons in a layer of porous SiC. The use of silicon carbide allows the gas sensor to function at the high temperatures typically found in automotive exhaust streams. While the mechanism of operation has not yet been adequately studied, the basis of operation of this sensor is that gases will dissociate at a characteristic potential on or in the active layer when the potential across the analyzing layer, porous silicon carbide, is varied. Carbon-hydrogen bonds in gas molecules adsorbed on the surface or on the walls of the pores are broken selectively by varying the applied field across this layer. This sensor may be built either as a field effect transistor (FET), in which ionic buildup at the insulation layer results in a variable depletion region below the gate, or as a capacitor. Early results indicate that different weight hydrocarbons will dissociate at different potentials, thus making it possible to identify the hydrocarbons. Gas concentrations are determined by reading the magnitude of current flow across the device, in the capacitor configuration, and through the channel, in the FET configuration.

2. Experimental setup

A prototype sensor composed of a porous SiC layer photoelectrochemically etched in an n type 6H-SiC wafer [3] (see inset in Fig. 1) has been fabricated and tested. The sensor structure is configured as a simple vertical construction of 6H-SiC with porous SiC as an active layer. A chromium grid was evaporated on the porous layer to provide an equipotential contact and a path for the diffusion of gas into the sensor; a nickel contact was deposited on

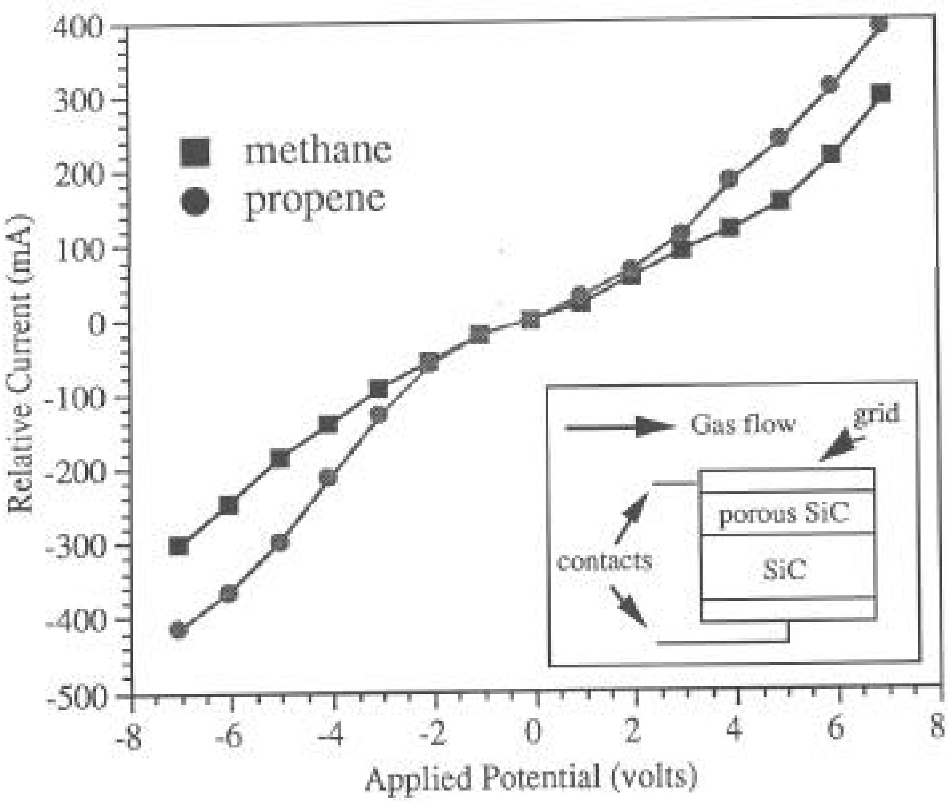

Figure 1. Current differences between methane and propene at 223°C, normalized to the argon reponse.

the unetched side of the SiC wafer. The sensor was placed inside a one meter long, 3.8 cm diameter quartz tube and mounted on an alumina heat spreader. A thermocouple was placed inside the alumina heat spreader directly below the sensor to measure the operational temperature. Gases were introduced into the tube at a rate of about 50 to 100 sccm. Experiments show the sensor's ability to distinguish among flows of an inert gas (Ar), and flows of pure hydrocarbons, methane and propene. Experiments in streams of the pure gases showed non-linear, reproducible differences in current-voltage curves, run from -7 to 7 V across the device. Figure 1 shows a plot of current vs. potential (iV) of pure methane and pure propene, normalized to the argon response, thus eliminating resistive effects in the current-voltage curves.

The iV curves taken in pure hydrocarbon gas and in 0.5% hydrocarbon in argon show that the magnitude of the iV response is proportional to the gas concentration. The non-linear nature of the iV curve will make it possible to discriminate among hydrocarbons as well as to

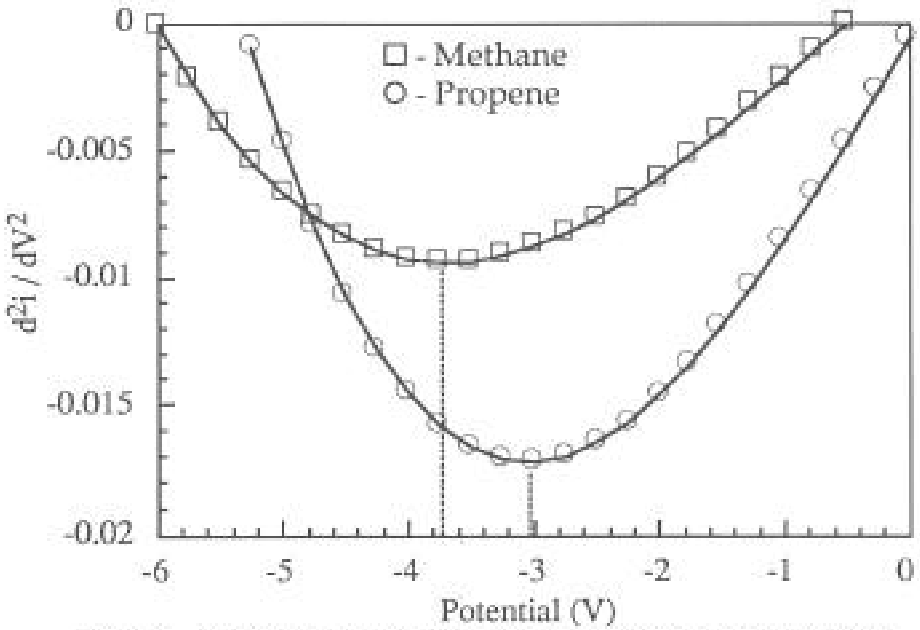

Figure 2. Second derivative of the current responses for methane and propene at 223°C, normalized to the argon response.

measure concentration. Identification of hydrocarbons can be accomplished by analysis of the iV curves. Figure 2 shows the second derivative (d^2i/dV^2) of the normalized iV curves in Figure 1. d^2i/dV^2 represents the change in conductance (di/dV) with changing potential. Derivatives were taken from a curve fitted to the data, as shown in Figure 1. The potentials of the minima in the second derivatives, shown in Figure 2, are characteristic of a particular hydrocarbon, and may be used to identify the compound. The magnitudes may be used to determine concentration. It is the identification of these characteristic minima which will make it possible to identify components of a mixed gas stream.

3. Conclusion

The porous SiC/SiC sensor described here offers the possibility of identifying hydrocarbons in a mixed gas stream on a single sensor. The sensor can operate at temperatures as low as 200°C, and will operate at higher temperatures (>500°C). Further work is required to understand the mechanism of operation of this device, although the identification of a characteristic potential for iV response indicates dissociation of the gas molecule. Early results have shown characteristic responses of pure streams of argon, methane and propene. The same characteristic potentials of d^2i/dV^2 minima were seen for pure propene and 0.5% propene in argon. Such a hydrocarbon gas sensor offers the ability to continuously monitor various concentrations of hydrocarbon gases in a wide range of thermal environments. The relatively low temperature at which the responses where measured along with the lack of use of catalytic materials in the fabrication offer the potential of a low cost sensor design.

References

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